2010 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING MINI-SYMPOSIUM
AUGUST 17-19 DEARBORN, MICHIGAN

Systems Engineering Processes Applied To Ground Vehicle Integration at US Army Tank Automotive Research, Development, and Engineering Center (TARDEC)

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ABSTRACT

The Center for Ground Vehicle Development and Integration (CGVDI) is a U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC) capability responsible for design, fabrication, integration, and support of additional capabilities for fielded systems as well as overall project management. CGVDI provides customers a single office that coordinates activities across the U.S. Army Research Development and Engineering Command (RDECOM) to conduct the complete spectrum of activities required to support Project Management Offices with design, development, integration, and testing of ground systems to meet the needs of the Warfighter. To better serve the organizations and programs supported by CGVDI, the TARDEC Systems Engineering Group worked to infuse Systems Engineering (SE) processes into CGVDI standard operating procedures as a way to effectively meet project cost, schedule, risk, and performance goals.

INTRODUCTION

The Center for Ground Vehicle Development and Integration (CGVDI) is a U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC) capability responsible for design, fabrication, integration, and support of materiel solutions required by Program Executive Office (PEO) and Program Management (PM) partners, as well as overall project management.

CGVDI provides the Department of Defense (DoD) a single project management office that coordinates activities across the U.S. Army Research Development and Engineering Command (RDECOM) and DoD to conduct the complete spectrum of activities required for design, development, integration and testing of ground systems (manned or unmanned) from engineering changes to technology/capability insertion to full system prototypes in order to meet the needs of the Warfighter.

To better serve the organizations and programs supported by the CGVDI, the TARDEC Systems Engineering Group worked with the CGVDI staff to infuse Systems Engineering (SE) processes into CGVDI standard operating procedures as a way to effectively meet project cost, schedule, risk, and performance goals.

This paper describes the processes used by the CGVDI during project execution and how SE processes are used to manage the technical project execution.

CENTER FOR GROUND VEHICLE DEVELOPMENT & INTEGRATION

The system engineering principles developed and utilized by CGVDI are best understood in the context of its Mission and Organization.

Mission and Scope

CGVDI was formed to leverage RDECOM and DoD capabilities in a repeatable process to apply rigorous systems engineering to ground systems integration. In doing so, it provides customer partners a single entry point for cost, schedule, performance and risk management of system integration projects.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
17 AUG 2010	**N/A**	

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Systems Engineering Processes Applied To Ground Vehicle Integration at US Army Tank Automotive Research Development, and Engineering Center (TARDEC)	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
; Yee AndrewBruce Brendle PhD	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000, USA	**20931RC2**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**6**	

Major Efforts

CGVDI and its processes have been applied successfully to do Mine Resistant Ambush Protected (MRAP) Capability Insertion for several MRAP variant systems, Command and Control on the Move (C2OTM) for both Stryker and MRAP variants, and the development of a Robotic Deployment System. Ongoing efforts include continued integration support for Joint Program Office (JPO) MRAP, upgrade of the Light Armored Vehicle Recovery variant and multiple efforts for the Robotic Systems Joint Project Office.

Organization

CGVDI acts as a virtual organization for most of its projects. While many of the required core competencies are either within the CGVDI organization or resident within TARDEC, CGVDI routinely leverages expertise and facilities from across RDECOM. Notable examples are Human Factors Engineering from the Army Research Laboratory and antenna co-site analysis from Communications-Electronics Research Development and Engineering Center (CERDEC).

Core Processes

To allow efficient execution of a system integration process across a distributed, virtual organization, CGVDI developed an overarching System Development & Integration process and a Program Definition process, both enabled by supporting system engineering processes.

System Development & Integration Process

The primary objective of the System Development & Integration process is to transform data, components and systems provided by CGVDI customers into fully integrated systems and associated technical data packages. Projects are executed within the constraints of both the customer (cost and schedule) and CGVDI (capabilities and capacity), as depicted in Figure 1.

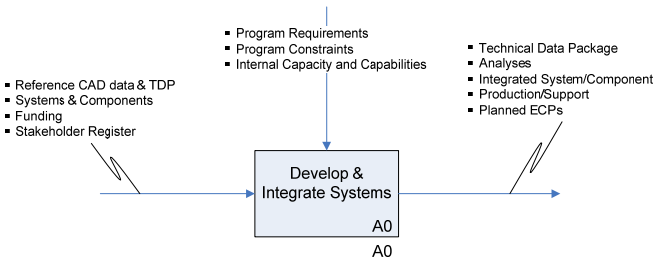

Figure 1: System Development & Integration Overview.

In order to completely understand the impacts of capability integration onto existing systems and the resulting performance of the integrated system, CGVDI utilizes a process, shown in Figure 2, of conceptual integration and analysis, followed by detailed design and analysis prior to fabricating, integration and testing the integrated system. The early use of modeling and simulation analyses allows stakeholders to guide the development and make informed decisions.

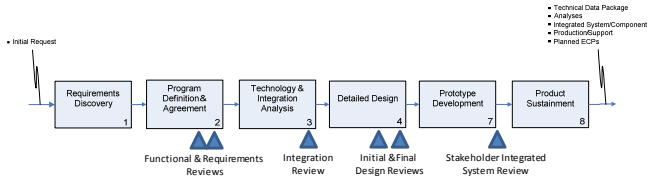

Figure 2: System Development & Integration Process.

Program Definition Process

A critical step to insure successful integration projects is to conduct a detailed program definition (Figure 3), generating standard system engineering artifacts. These artifacts, including the Project Baseline, Requirements Documentation, and Risk Management Plan, form the basis for project execution.

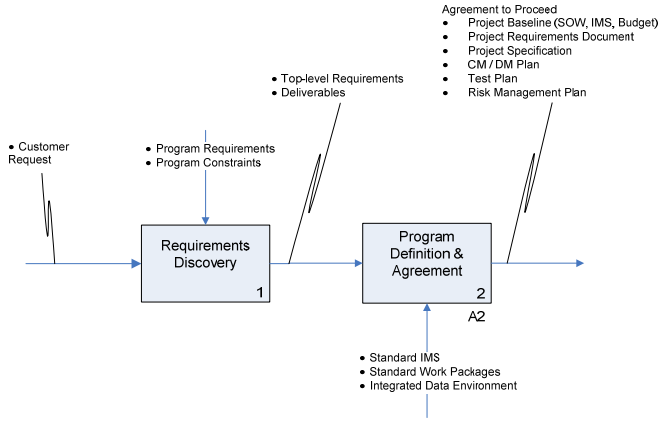

Figure 3: Program Definition Process.

SYSTEMS ENGINEERING INTEGRATION

In recent years, an effort to revitalize Systems Engineering in the Department of Defense (DoD) has gained momentum in many organizations. One such organization within the U.S. Army RDECOM is the TARDEC Systems Engineering Group (SEG). The SEG was established in May 2007, in support of the DoD "SE revitalization" effort, as a means to apply SE principles to the Army's Ground Vehicle development process. Since the SEG's formation, several TARDEC business areas have benefited from the SEG's effort to apply SE planning and processes to enhance the technical effort involved in the Army's Ground Vehicle

development process. One such business area, that is actively integrating SE principles within their operation, is the CGVDI.

The SE Technical and Technical Management Processes shown in Figure 4 are sources of SE principles embedded throughout the CGVDI System Development and Integration process.

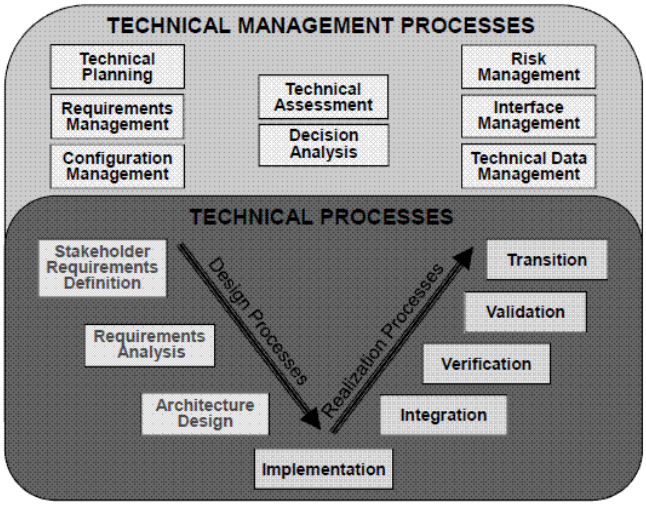

Figure 4: DoD SE Process Model 2009 [1].

The following sections describe which SE Technical and Technical Management Processes have been implemented within the CGVDI, along with the level of functionality and the benefits achieved.

Technical Planning

The TARDEC Systems Engineering Group infused SE processes into the CGVDI System Development & Integration process to enhance the overall technical effort needed to execute CGVDI projects. A Systems Engineering Plan (SEP) was created during this process development period to identify the SE principles that should be embedded throughout the CGVDI Systems Development and Integration process, and also, to plan the implementation and use of these SE principles during the project execution lifecycle.

The SE processes, identified during this planning phase, that have an immediate impact on project execution effectiveness include Requirements Management, Technical Assessment, Decision Analysis, and Risk Management, which are described in the subsequent sections.

Requirements Management

Projects that are managed by the CGVDI need to incorporate a mechanism to effectively organize and communicate project requirements to the resources that execute tasks necessary for successful project completion. The SEG currently uses requirements management software to manage project requirements. This software application allows users to effectively capture, organize, analyze, and trace project requirements in the effort to successfully deliver a project to the CGVDI partner/customer that complies with the defined project requirements. The SEG is currently implementing this Requirements Management solution on an MRAP integration project to use as a template for future CGVDI projects.

Requirements Definition

Project Requirements are gathered from sources such as project statement of work, customer input/documents, system requirements, derived requirements, lessons learned, etc. This collection of requirements is used to describe a project's needs, and form the basis for a project's architecture/design solution. The TARDEC SEG developed an information model, depicted in Figure 5, which graphically describes a logical flow for developing project requirements, allocating requirements for solution design, and verifying requirement compliance.

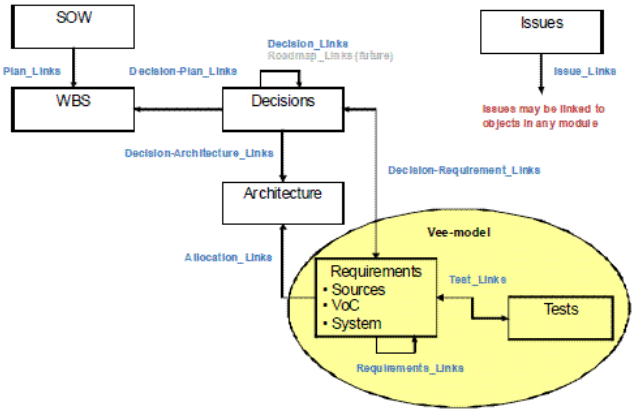

Figure 5: TARDEC SEG Information Model.

Figure 5 shows the contents of the information model and the relationships between the various logical groupings containing similar information. The contents of the information model are housed in the requirements management software described earlier.

The model shows that the Statement of Work ("SOW") received at project initiation helps to define the tasks that need to be accomplished in the Work Breakdown Structure ("WBS"). The information contained in the "Decisions" area helps to answer questions and provides rationale related to why certain solutions were chosen in the "Architecture" area, and also, why certain "Requirements" are defined and necessary. The "Requirements" information is linked to the

"Tests" information to show verification of compliance. The "Requirements" section also links to the "Architecture" section to show the allocation of requirements to resources that develop design solutions that satisfy the overall system requirements.

Requirements Analysis

Many times the requirements received from the CGVDI partners/customers are very high level and general in nature, and therefore, less useful for project definition. These requirements must be decomposed into statements that are singular, concise, unambiguous, and verifiable so project solutions can be designed to meet the customer's desired outcome. Each requirement is reviewed, analyzed, and validated by the CGVDI Project Leads along with their supporting resources. This analysis activity culminates in a Project Requirements Review, explained in the next section, to obtain project requirements agreement between all involved organizations.

Requirements Traceability is also a part of the Requirements Analysis process. This involves using the requirements management software to link requirements to verification methods ("Tests" in Figure 5) and solutions ("Architecture" in Figure 5). This linking will allow users to easily determine if gaps exist in addressing each requirement that contribute to the overall project definition.

Technical Assessment

To add rigor to the CGVDI project execution process, Technical Reviews have been integrated into the System Development and Integration process. These Technical Reviews utilize Entry/Exit Criteria to prepare for and complete each review as part of the standard process to increase the effectiveness of each required review. During each Technical Review, as required and documented in the CGVDI SEP, the Approval Authority defined for each review evaluates the Entry/Exit Criteria during the course of the review and decides the outcome (Pass, Fail, Pass with Follow-Up).

Technical Reviews are used in the course of defense acquisitions as described in the Defense Acquisition Guidebook (DAG) [2]. Some of the Technical Reviews listed in the CGVDI SEP for use on each project are tailored versions of the standard reviews described in the DAG. These tailored reviews used by the CGVDI are shown below with a brief description and a reference to the corresponding standard review, if applicable:

- Project Requirements Review (Tailored from System Requirements Review) - Review project requirements to ensure that they are properly defined.
- Project Functional Review (Tailored from System Functional Review) - Ensure that the system under review can proceed into preliminary design, and that all project requirements and functional performance requirements are defined.
- Integration Review - Review conceptual integration design and supporting analyses with project stakeholders to receive approval to proceed to detailed design. (Progress Review 1.0 is conducted prior to this formal review to ensure readiness for Approval Authority decision).
- Initial Design Review (Tailored from Preliminary Design Review) - Review initial mechanical, electrical, and software design with project stakeholders to receive approval to proceed to final design. (Progress Review 2.0 is conducted prior to this formal review to ensure readiness for Approval Authority decision).
- Final Design Review (Tailored from Critical Design Review) - Review final mechanical, electrical, and software design with project stakeholders to receive approval to proceed to fabrication, demonstration, and test. (Progress Review 3.0 is conducted prior to this formal review to ensure readiness for Approval Authority decision).
- Risk Management Reviews - Review risks and risk mitigation plans for project risks prior to each formal review listed above.
- Stakeholder Integrated System Review (Tailored from Test Readiness Review) - Review fully integrated system with all stakeholders prior to project delivery.
- Functional Verification Audit (Tailored from Functional Configuration Audit) - Review fully integrated project to verify functionality before delivery to partner/customer.

Decision Analysis

Many CGVDI projects require alternative solution evaluations to determine the best solution for implementation based on a predetermined set of criteria. The TARDEC SEG uses several tools to aid in this evaluation process. One method used for equipment selection was a Technology Selection Matrix. A generic Technology Selection Matrix template is shown in Figure 6. This matrix consisted of three main selection criteria categories; performance, schedule, and cost. Each category contains a set of criteria and scoring value guidance based upon criteria values or range of values. The criteria are ranked for relative importance to each other. (Value of 1 to 10, with 10 being the highest). Further, each category is given a weighting factor to compare the relative importance

of the categories with each other. (Percentage value where the total of all categories equals 100%).

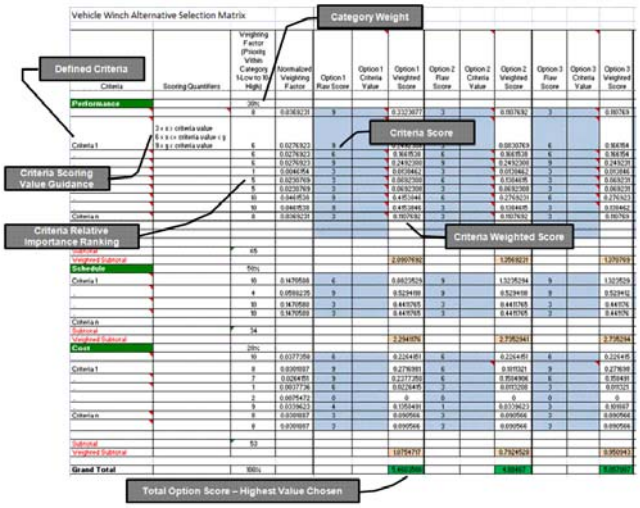

Figure 6: Technology Selection Matrix Template.

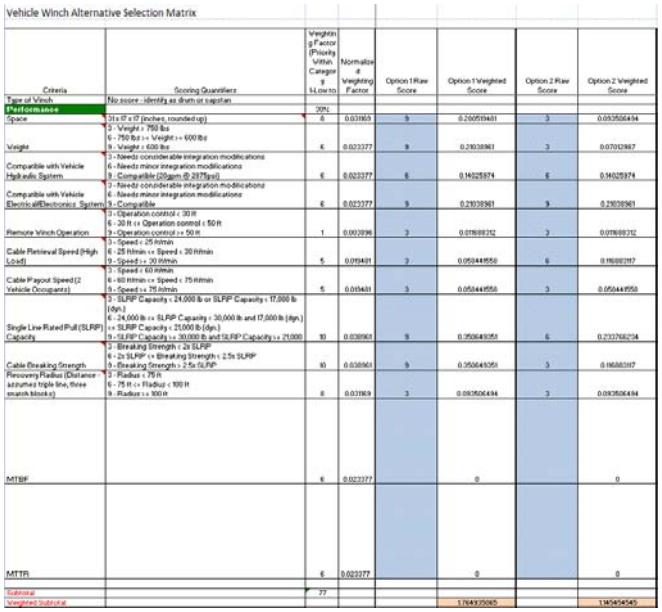

Figure 7: Technology Selection Matrix - Example.

The matrix is populated with technology options and scored using the criteria and criteria scoring value guidance. The raw score is converted to a weighted score using the criteria relative importance ranking and category weight factors. When all options have been evaluated against all of the criteria, the total option scores are compared and the option with the highest value is selected. This selection method allows an objective process to be used to compare and choose the best option using mutually agreed upon criteria.

An example of a Technology Selection Matrix that was used on a project is shown in Figure 7.

Risk Management

CGVDI projects are continuously evaluated to identify risks that may jeopardize project completion. Risks are evident in areas of performance, cost, and schedule. The risk process usually consists of identifying risks, assessing risks, mitigating risks, and monitoring risks.

The TARDEC SEG has integrated a Risk Management Process into the CGVDI System Development and Integration process. The TARDEC SEG utilizes a Risk Management application called "Risk Recon" (See Figure 8), which was developed by PEO Ground Combat Systems (GCS), to document risks [3]. Risks are inputted into Risk Recon by the CGVDI Project Leads or any project support resources. These risks are then reviewed for clarity and completeness by the Risk Manager, who is a member of the TARDEC SEG. A Risk Review Board reviews the submitted risks and evaluates the risk validity, mitigation plan, and resource needs.

The risks are organized by projects (See Figure 9) within the Risk Recon tool and access is controlled by the Risk Administrators. When a Risk Recon project is accessed, the view shows all of the risks with a status summary (See Figure 10) and a field that is color-coded with the Risk Assessment information (See Figure 11) showing likelihood and consequence of the risk (future event) becoming an issue (event that has already occurred).

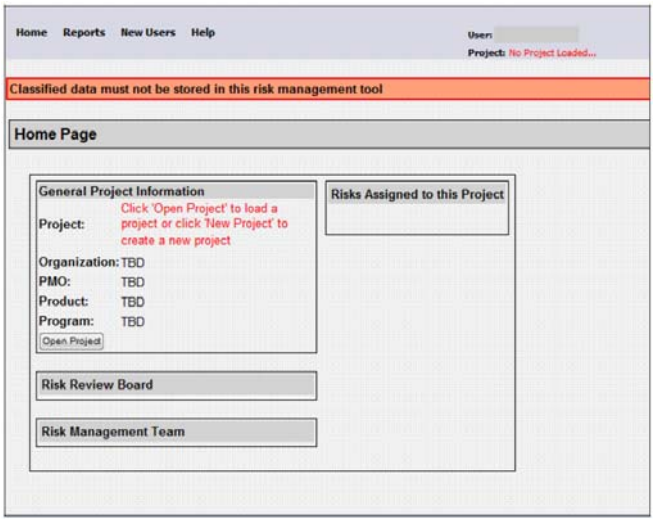

Figure 8: Risk Recon Tool - Home Page.

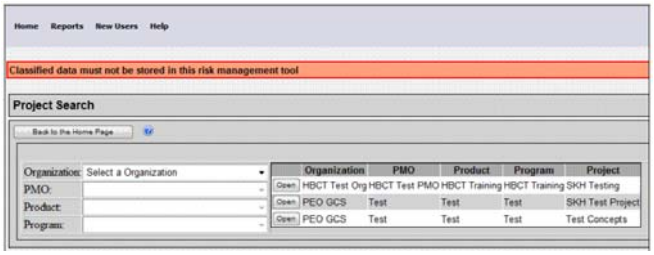

Figure 9: Risk Recon Tool - Project View.

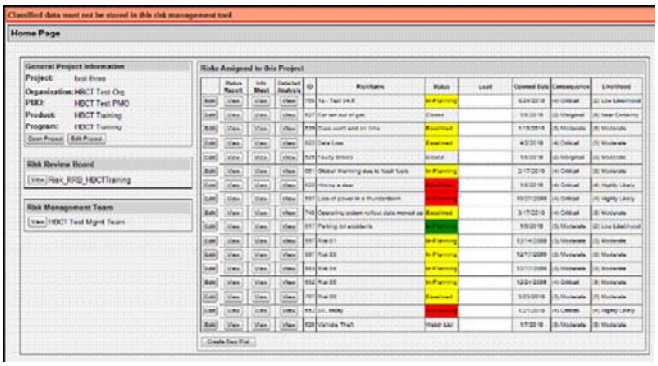

Figure 10: Risk Recon Tool - Risk Summary View.

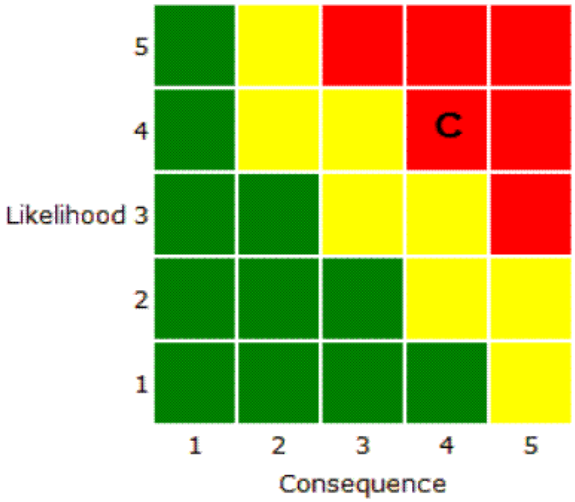

Figure 11: Risk Recon Tool - Risk Assessment Color-Code

CONCLUSION

The effort to revitalize Systems Engineering in the Department of Defense (DoD) is continuing to gain momentum at TARDEC through the help of the Systems Engineering Group. As processes continue to mature and become formalized, these efforts will be implemented throughout the organization, especially in areas such as the Center for Ground Vehicle Development and Integration, whose use of their System Development and Integration process, has become an excellent implementation of the Systems Engineering Process Model.

REFERENCES

[1] Defense Acquisition University (DAU), "Technical Leadership in Systems Engineering", DAU, 2010.

[2] Defense Acquisition University (DAU), "Defense Acquisition Guidebook", Chapter 4 - Systems Engineering, DAU, 2010.

[3] PEO GCS G6 Office, "Risk Recon Tool User's Guide", PEO GCS G6 Office, 2010.